Spin effects in diffractive hadron photoproduction

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Abstract. We study spin asymmetries in diffractive $Q\bar{Q}$ and vector meson production which are sensitive to the spin-dependent part of the two-gluon-nucleon coupling. It is found that the A_{ll} and A_{lT} asymmetry in diffractive reactions can be used to study polarized gluon distributions of the proton.

I INTRODUCTION

Investigation of the structure of hadrons, is a problem of considerable interest now. The inclusive reaction can be used to study ordinary parton distributions. However, it is difficult to distinguish events with a single outgoing proton or jet in a fixed target experiment like COMPASS [1]. In this case, at small x the diffractive events will contribute together with nondiffractive one. The measured asymmetry can be written in the form

$$A_{exp} = \frac{\Delta\sigma_{ND} + \Delta\sigma_D}{\sigma_{ND} + \sigma_D} = A(1-R) + A_D R, \quad R = \frac{\sigma_D}{\sigma_{ND} + \sigma_D}. \tag{1}$$

Here $A = \Delta\sigma_{ND}/\sigma_{ND}$ and $A_D = \Delta\sigma_D/\sigma_D$. It can be shown that the ratio R should increase with $x \to 0$. The integrated over x R ratio has been found at HERA to be about 20–30% [2]. This means that diffractive events might be important in extraction of asymmetry at small x from experiment. The diffractive hadron photoproduction can be expressed in terms of skewed parton distribution (SPD) in the nucleon $\mathcal{F}_\zeta(x)$ [3]. Investigation of such diffractive reactions should play a keystone role in future study $\mathcal{F}_x(x)$ at small x. In the diffractive charm quark production including J/Ψ reactions, the predominant contribution is determined by the two-gluon exchange (gluon SPD). Analysis of these reactions should throw light on the gluon structure of the proton at small x [4,5].

To study spin effects in the diffractive hadron production, one must know the structure of the two-gluon coupling with the proton at small x. The QCD–inspired diquark model generates the spin-dependent ggp coupling [6] of the following form:

$$V_{pgg}^{\alpha\alpha'}(p,t,x_P,l_\perp) = (\gamma^\alpha p^{\alpha'} + \gamma^{\alpha'} p^\alpha) B(t,x_P,l_\perp) + 4p^\alpha p^{\alpha'} A(t,x_P,l_\perp) + \epsilon^{\alpha\beta\delta\rho} p_\delta \gamma_\rho \gamma_5 D(t,x_P,l_\perp). \quad (2)$$

The first two terms of the vertex (2) are symmetric over α, α' indices. The structure $(\gamma^\alpha p^{\alpha'} + \gamma^{\alpha'} p^\alpha) B(t)$ in (2) determines the spin-non-flip contribution. The term $p_\alpha p_{\alpha'} A(r)$ leads to the transverse spin-flip in the vertex which does not vanish in the $s \to \infty$ limit. The single spin transverse asymmetry predicted in the models [6,7] is about 10% for $|t| \sim 3\mathrm{GeV}^2$ which is of the same order of magnitude as has been observed experimentally [8]. These model approaches give for the ratio $\alpha = A/B \leq 0.1\mathrm{GeV}^{-1}$

The asymmetric structure in (2) is proportional to $D\gamma_\rho\gamma_5$ and can be associated with ΔG. It should give a visible contribution to the double spin longitudinal asymmetry A_{ll} [9]. The value of this structure is not well known now from our model estimations.

In this report, we shall analyze spin effects caused by the structures A and B. It will be shown here that such effects will be small in the A_{ll} asymmetry. The double spin asymmetry for a longitudinally polarized lepton and a transversely polarized proton is predicted to be not small and mainly determined by the A term in (2). Such asymmetry should be used to study this structure in the ggp coupling.

II DIFFRACTIVE HADRON PRODUCTION AND SPD

Let us study the diffractive J/Ψ production at high energies and fixed momentum transfer. The fractions of the momenta of proton carried by the Pomeron, $x_P \sim (m_J^2 + Q^2 + |t|)/W^2$ is small at high energies. The $\gamma^\star \to J/\Psi$ transition amplitude is described by a nonrelativistic wave function [4,10]. Gluons from the Pomeron are coupled with the single and different quarks in the $c\bar{c}$ loop. The spin-average and spin dependent cross sections of the J/Ψ leptoproduction with parallel and antiparallel longitudinal polarization of a lepton and a proton are determined by the relation

$$\frac{d\sigma(\pm)}{dQ^2 dy dt} = \frac{1}{2} \left(d\sigma(\overset{\rightarrow}{\leftarrow}) \pm d\sigma(\overset{\rightarrow}{\Rightarrow}) \right) = \frac{|T^\pm|^2}{32(2\pi)^3 Q^2 s^2 y}.. \quad (3)$$

For the spin-average amplitude square we find [11]

$$|T^+|^2 = s^2\, N \left((2 - 2y + y^2) m_J^2 + 2(1-y) Q^2 \right) \left[|\tilde{B} + 2m\tilde{A}|^2 + |\tilde{A}|^2 |t| \right]. \quad (4)$$

Here the term proportional to $(2 - 2y + y^2) m_J^2$ represents the contribution of the virtual photon with transverse polarization. The $2(1-y)Q^2$ term describes the effect of longitudinal photons. The N factor in (4) is normalization, and the $\tilde{A}$ and $\tilde{B}$ functions are expressed through the integral over transverse momentum of the gluon. The function $\tilde{B}$ is determined by

$$\tilde{B} = \frac{1}{4\bar{Q}^2}\int \frac{d^2l_\perp(l_\perp^2+\vec{l}_\perp\vec{\Delta})B(l_\perp^2,x_P,...)}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{\Delta})^2+\lambda^2)[l_\perp^2+\vec{l}_\perp\vec{\Delta}+\bar{Q}^2]}$$

$$\sim \frac{1}{4\bar{Q}^4}\int_0^{l_\perp^2<\bar{Q}^2} \frac{d^2l_\perp(l_\perp^2+\vec{l}_\perp\vec{\Delta})}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{\Delta})^2+\lambda^2)}B(l_\perp^2,x_P) = \frac{1}{4\bar{Q}^4}\mathcal{F}^g_{x_P}(x_P,t,\bar{Q}^2). \quad (5)$$

and connected with the gluon SPD [12]. Here $\bar{Q}^2 = (m_J^2+Q^2+|t|)/4$. The $\tilde{A}$ function is determined by the similar integral. The spin-dependent amplitude square looks like

$$|T^-|^2 = s|t|(2-y)N\left[|\tilde{B}|^2 + m(\tilde{A}^\star\tilde{B}+\tilde{A}\tilde{B}^\star)\right]m_J^2. \quad (6)$$

The asymmetry $A_{ll} = \sigma(-)/\sigma(+)$ depends on the ratio of the spin-flip to the non-flip parts of the coupling (2) $\alpha_{flip} = \tilde{A}(t)/\tilde{B}(t)$ which has been found to be about 0.1. The predicted asymmetry at HERMES energies is shown in Fig. 1. The contribution of the spin-dependent A term in (2) to the double spin A_{ll} asymmetry of the J/Ψ production does not exceed two per cent for the momentum transfer $|t| \leq 1\mathrm{GeV}^2$. Sensitivity of the asymmetry to α is rather weak. At HERA energies, the asymmetry will be negligible.

For the diffractive $Q\bar{Q}$ leptoproduction the spin-average and spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2dydx_Pdtdk_\perp^2} = \binom{(2-2y+y^2)}{(2-y)}\frac{C(x_P,Q^2)\;N(\pm)}{\sqrt{1-4k_\perp^2\beta/Q^2}}. \quad (7)$$

Here $C(x_P,Q^2)$ is a normalization function which is common for the spin average and spin dependent cross section. The $N(\pm)$ functions are expressed through the

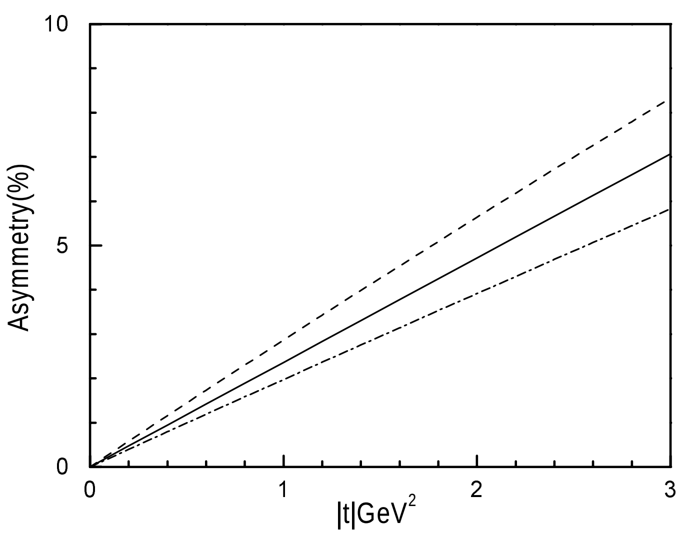

FIGURE 1. The A_{ll} asymmetry of the J/Ψ production at HERMES: solid line -for $\alpha_{flip} = 0$; dot-dashed line -for $\alpha_{flip} = -0.1$; dashed line -for $\alpha_{flip} = 0.1$

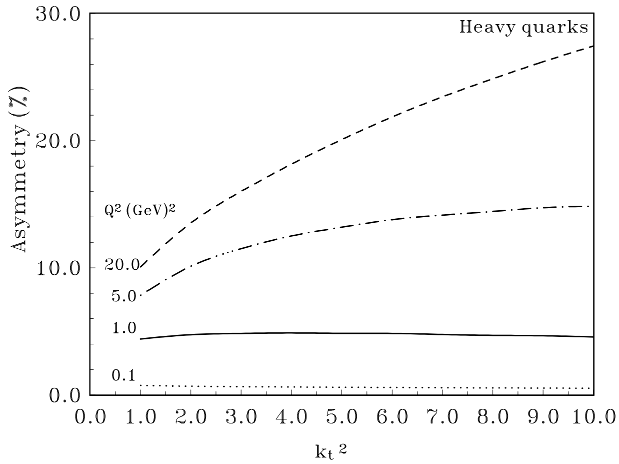

FIGURE 2. The predicted Q^2 dependence of the A_{lT} asymmetry for the $c\bar{c}$ production at COMPASS for $\alpha = 0.1\mathrm{GeV}^{-1}$, x_P=0.1, y=0.5

same skewed gluon distributions $\mathcal{F}^g_{x_P}(x_P, t, \bar{Q}_1^2)$ as for vector meson production but at a different scale $Q_1^2 = m_Q^2 + k_\perp^2$ (k is a quark momentum). Note that x_P is not fixed in this reaction and usually $x_P \leq 0.1$ The predicted asymmetry is quite small and does not exceed 1%. It has a week dependence on the $\alpha = \tilde{A}/\tilde{B}$ ratio. Moreover, the A_{ll} asymmetry is predicted to vanish for $Q^2 \to 0$ as $A_{ll} \propto Q^2/(Q^2 + Q_0^2)$ with $Q_0^2 \sim 1\mathrm{GeV}^2$.

The A structure in (2) should contribute to the A_{lT} asymmetry with longitudinal lepton and transverse proton polarization. The calculation of this asymmetry is similar to the analysis of A_{ll}, which has been carried out before. It has been found that the A_{lT} asymmetry is not small and proportional to the $\alpha = \tilde{A}/\tilde{B}$ ratio. The A_{lT} asymmetry is proportional to the scalar production of the proton spin vector, and the jet momentum $A_{lT} \propto (s_\perp \cdot k_\perp) \propto \cos(\phi_{Jet})$ and the asymmetry integrated over the azimuthal jet angle ϕ_{Jet} is zero. We have calculated the A_{lT} asymmetry for the case when the proton spin vector is perpendicular to the lepton scattering plane and the jet momentum is parallel to this spin vector. The predicted asymmetry is large and shown in Fig. 2. The reason for the large value of A_{lT} is that we do not find here a small coefficient x_P as for the A_{ll} asymmetry [13].

III CONCLUSION

In the present report, the polarized cross section of the diffractive hadron leptoproduction at high energies has been studied. The two-gluon exchange model with the spin-dependent gg-proton coupling (2) has been used. We consider all the graphs where the gluons from the Pomeron couple to a different quark in the loop and to the single one. This provides a gauge-invariant scattering amplitude.

Our calculations show that the contribution of the structure A in (2) to A_{ll} is smaller than 1-2%. Not small effects in the double spin A_{ll} asymmetry should be determined by the $\Delta G \propto D\gamma_\rho\gamma_5$ term of the vertex (2). The results obtained here show that diffractive asymmetry in the $Q\bar{Q}$ production vanishes as $Q^2 \to 0$. We can conclude that most likely such effects do not provide additional problems in extracting ΔG from the A_{ll} asymmetry because the COMPASS experiment plans to study the open charm production at small Q^2 [1].

It is shown that the gluon SPD $\mathcal{F}^g_{x_P}(x_P)$ and connected with ΔG distribution $\mathcal{G}^g_{x_P}(x_P)$ at the small $x_P \sim (m_V^2 + Q^2)/W^2$ can be studied from the double spin asymmetry in the vector meson photoproduction. The contributions of the quark SPDs are non-negligible for x of about 0.1 where the HERMES and COMPASS experiments will operate. Thus, in the case of the ϕ production the strange quark SPD might be studied in addition to the gluon one.

It is found here that the A_{lT} asymmetry of the diffractive heavy quark production is predicted to be not small, about 10-20%. It can give direct information about the spin-dependent structure A in the ggp coupling. A similar contribution to A_{lT} in the vector meson production vanishes because of the integration over $k_\perp$. The structure, which is proportional to x_p in the A_{lT} asymmetry of the vector meson production will be studied later.

We can conclude that important information on the spin–dependent SPD at small x can be obtained from double spin asymmetries in diffractive hadron photoproduction reactions .

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